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## STEPS TOWARDS A NEW PRINCIPIA.

*Electricity and Matter.* By Prof. J. J. Thomson. Pp. 162; with diagrams. (Westminster: Archibald Constable and Co., Ltd., 1904.) Price 5*s*. net.

IT is an interesting fact that the British Association is going so soon to meet, under distinguished presidency, at Cambridge, for there of late years has the most splendid work in pure physical science been done, and there it seems to me an erection comparable in some respects to the Principia is being raised. One of the foundation stones was laid in 1881 by J. J. Thomson in a mathematical paper on the motion of a charged sphere, a paper in which the idea of real electric inertia took tangible and tractable form. The building has been growing ever since, and is now in full process of construction, though I hope it will be long before its development shall cease or the work be regarded as finished and ready to be left to the admiration of future generations.

The little book which constitutes the subject-matter of this review embodies a set of six lectures delivered on the other side of the Atlantic, at the invitation of Yale University, last spring, by the Cavendish professor of physics at Cambridge, England.

They are not exactly popular, for although no mathematics is introduced beyond what ought to be (but usually is not) familiar to all who have been in the sixth form at a public school, yet the ideas are definite and quantitative, and are briefly expressed because they are addressed to persons with some knowledge of physics; moreover, they are such as can hardly be made so childishly simple as to be apprehended of the general average of so-called educated men in this country, whose sense-perceptions in the direction of great and comprehensive ideas have not been developed.

To students of physics and higher chemistry this book serves as a very readable digest and summary of what is to be found worked out in more detail in other writings by the same author; and those who have studied his most recent papers can hardly avoid reading back into this little volume, which can be skimmed at a sitting, much that has really been elaborated since, and some things which still await elaboration, on lines which are merely suggested here.

It is difficult to exaggerate the suggestiveness of the wealth of theory which is now being lavished upon us in the domain of atomic structure and the mathematics of chemistry; it appears likely to lead to a definite microcosmic astronomy, based upon the known properties of electric lines of force, akin to the welding together of the observed facts of the heavens by a single comprehensive law, and forming the basis of a real chemical "Principia."

The discovery on which everything depends is the recognition of the atom of electricity, a discovery to which no one man can lay claim, and superposed upon this a detection of the extraordinary properties belonging to an electric line of force, at rest, in motion, and under acceleration, which is again a development to which several have contributed. But it is safe to say that a great bulk of the treatment of the subject, both on its experimental and mathematical side, emanates, with a few important exceptions, in some form or other from Cambridge, and it is difficult to overestimate the force and suggestiveness with which ideas connected with the most recent and still nascent steps in theory are presented in this small book.

The book is in six chapters, corresponding apparently with six lectures.

Chapter iv., on the atomic structure of electricity, gives the customary account of the evidence for electric atoms, and for considering the charge on a corpuscle to be identical with the ionic charge of a hydrogen atom; the experiments by which these conclusions were reached in the Cavendish Laboratory being summarised and explained on the usual lines. First, it was shown that the conductivity of a gas depended on something that could be filtered out of it; next, the aggregate charge of the ions in a given volume of gas was determined by the method of the saturation current; then these ions were counted by the highly ingenious "cloud" method, and thus the charge on each determined. The value, it may be noted in passing, is rather higher than what used to be roughly estimated for this fundamental electric unit. Whereas it used to be guessed as about $10^{-11}$ electrostatic units, measurement seems to show that it is more nearly $3.4 \times 10^{-10}$; and, in order to make this quantity equal to the charge on a monad ion in electrolysis, the number of molecules in a cubic centimetre of gas, at standard temperature and pressure, must be rather fewer than used to be estimated as probable, and also rather definite, being about $3.6 \times 10^{19}$, which means $8 \times 10^{23}$ atoms of hydrogen per gram.

A new confirmatory method applied by Dr. H. A. Wilson is described, in which the settling of a cloud under gravity is opposed by a measured electric field; and on this plan the same result is obtained. Also Prof. Townsend and Dr. H. A. Wilson, by applying electrolytic considerations and experiments to ionised air, were able to show directly that the ionic charges in all cases are really identical, and are the same as that familiar in electrolysis.

A rapid summary of the now well known methods by which the mass of the carriers for negative and for positive electricity respectively has been determined is also given, and it is pointed out how striking is the resemblance of the result to Franklin's one-fluid theory of electricity:—

"The 'electric fluid' of Franklin corresponds to an assemblage of corpuscles, negative electrification being a collection of these corpuscles. The transference of electrification from one place to another is effected by the motion of corpuscles from the place where there is a gain of positive electrification to the place where there is a gain of negative. A positively electrified body is one that has lost some of its corpuscles. We have seen that the mass and charge of the corpuscles have been determined directly by experiment. We in fact know more about the 'electric fluid' than we know about such fluids as air or water."

The next chapter (v.), on the constitution of the atom, begins still on familiar ground, and exhibits the evidence for the great intrinsic energy of electrically constituted atoms, and estimates the rate of radiation of energy from corpuscles variously distributed inside an atom, showing that the radiation from a single corpuscle is far greater than that to be expected from two or more, especially when their speeds are not excessive. [It may be observed that a pair of revolving electrons, at opposite ends of a diameter, will be equivalent to two equal opposite currents, and hence will tend to neutralise each other's influence at a distance, especially along the axis of revolution; unless indeed they are moving with the speed of light, in which case they could start the crest and trough of an advancing elliptically-polarised wave.] Hence a certain number of corpuscles are essential to the stability of an atom, a few would soon radiate their energy away; and this fact, on the doctrine of the evolution of matter, suggests a reason for the non-existence of permanent elements of lower atomic weight than hydrogen.

But a great deal more than that is made out towards the end of the chapter, where the electric constitution of the atom is applied to chemistry, and a beginning of the explanation of "the periodic law" is made in this chapter which is further developed by the author in a great paper in the March number of the *Philosophical Magazine* for the present year. Also the homologous series of lines in the spectrum, investigated by Rydberg, Runge and Paschen, and Kayser, is shown to be a fairly natural, or at least plausible, consequence of the groupings of various numbers of corpuscles or electrons inside an atom; though it must be admitted that unless attention is paid to the modern view that concussions and not regular motions are the real cause of perceptible visible radiation and line spectra, the theory remains obviously very incomplete. The mode in which the corpuscles would statically distribute themselves, if they were limited to a plane, under the combined action of a mutual inverse square repelling force and a direct-distance central attracting force, is treated much as Lord Kelvin had already treated it in his remarkable paper called "Æpinus atomized" (reprinted as an appendix in his Baltimore Lectures), and is illustrated by Alfred Mayer's experiments on floating magnets; and the deductions, although plainly only the nucleus of an investigation, are already very suggestive and promising. In the March *Philosophical Magazine* the investigation into the stability of moving electrons is carried much further, and a distinct step is made in mathematical chemistry.

One very simple and important remark is made near the end of chapter v. concerning the "bonds" of the chemist, which, being, I suppose universally recognised as Faraday lines of electric force, must differ from ordinary stretched elastics in having opposite properties at the two ends. The bonds, in fact, must have "sense" as well as direction, they are not simple links; and hence when carbon atoms are linked together those atoms cannot really have identical properties, unless indeed they are linked to each other by an even number of bonds. Incidentally it becomes clear—at any rate in the March *Phil Mag.* it becomes clear to me—why carbon or tetrad atoms can link themselves into complex molecules: the foundation of organic chemistry.

A suggestion is also made concerning certain "additive" properties, such as the refractive power of different substances for light, which students of physical chemistry will do well to take up and press further.

The obvious question as to how an electrically constituted atom can acquire an additional charge, so as to become an ion, either positive or negative, and either monad, dyad, or triad, is discussed, and a guess is made as to the nature of molecular combination. It is also attempted to explain why a liquid, say liquid mercury, is so immensely better a conductor than mercury vapour, and why some gases may be conductors and others not. The violent motion of corpuscles going on inside an atom is styled by J. J. Thomson the "corpuscular temperature" of the atom, which may or may not be a convenient term; the ordinary temperature of the gas, called "molecular temperature," is generally very much smaller, and has no apparent relation with the corpuscular temperature. By the interaction of these two temperatures on one another, an attempt is made to account for certain chemical facts of combination. The whole of the chapter is so concentrated and full of suggestion that it is impossible effectively to abstract it further. What I wish to indicate to students is the desirability of studying the original.

Prof. Poynting has on this point made a remark to me which he permits me to incorporate, viz., that at high molecular temperatures there must be some distinct correspondence between molecular and corpuscular temperatures. For in the sun corpuscles are set free by collisions [as they may also be set free by the clash of chemical combination at more ordinary temperatures, a bright line spectrum resulting in both cases from the perturbation of those corpuscles which, although shocked, escape separation]. There would appear to be some high temperature at which the atoms go to pieces—a limiting molecular temperature beyond which they cannot exist (an atomic dissociation temperature), not *much* higher probably than the solar temperature. It is worthy of remark that no star is much hotter than the sun: possibly none so high as ten thousand degrees centigrade. If not, why not? unless it be because there is a natural limit at which matter goes to pieces.

The final chapter, on radio-activity and radio-active substances, emphasises the way in which atomic collapse, or re-distribution of corpuscles—a sort of atomic earthquake—may occasionally occur, after the radiation of a certain amount of energy has gone on for some time, by spontaneous re-arrangement of the constituents into a more stable form. For since orbital motion plainly tends to increase stability, enabling a greater number of corpuscles to resist central attraction than could hold out if they were stationary, it follows that, as the corpuscles slow down, they may at certain critical stages find it necessary to fall into

an allotropic modification of the element, or else to expel some and re-arrange the remainder; the analogy being a spinning top which tumbles over when its velocity falls below a certain critical value. [Some varieties of "new star" may conceivably furnish another and different kind of analogy.]

A new suggestion also is made with respect to Röntgen rays, viz. that they may sometimes precipitate atomic disintegration and thus cause a substance to emit more energy than they themselves contain. It is also pointed out in a previous chapter how a shell of Röntgen radiation will not disturb particles over which it passes if it is below a certain thickness, but if thicker than that will communicate momentum to them; and in that way a kind of modified Le Sage's gravitation hypothesis is suggested, not, however, in a convincing manner, but rather as one of the possibilities that have to be discussed, and after further consideration probably abandoned. At the same time, the hypothesis concerning radium favoured by Lord Kelvin, viz. the reception of energy from a store of cosmic waves and the consequent production of radioactivity, is shown to be in many respects feasible, though taken all round unlikely and rather artificial.

But the most remarkable and novel portion of the book is the use made of Faraday's lines of force, and the great development and importance attached to them, in the first three chapters. Strangely enough, these lines are for the first time regarded as realities; no longer as a mere map of a state of things which is essentially continuous, but as an actual fibrous structure attributable to an electric field, and therefore also to a magnetic field, and therefore also to radiation. The lines of force are not only *like* elastic threads which repel each other, but really are such threads, though with varying thickness and with their tension everywhere proportional to their cross-section; and it seems possible to think of them as vortex filaments, thus reproducing in many respects FitzGerald's conception of a fibrous vortex ether consisting of filamental or cobweb vortices interlaced in every direction (see preface to "Modern Views of Electricity," 1889), only these do not become lines of force unless they are cut and terminated; the newer view regards the place where their intense ends terminate as a negatively charged corpuscle or electron, their wider opposite ends appearing to correspond with positive electricity, the nature of which, however, still remains a close secret. This seems to be J. J. Thomson's view—though it is not clear that he regards the vorticity as anything more than an analogy—his view is that the lines of force or vortex fibres actually exist, radiating from corpuscles, constituting electric lines of force, generating magnetic fields when they move, and conferring mass on the particle by reason of the amount of ether entangled inextricably in each filament; and he shows further how, when the fibres are accelerated, especially when they are suddenly started or stopped, a much more intense local magnetic field for a moment makes its appearance and rapidly spreads out as a wave of radiation, by reaction with the superposed electric field, just as Larmor and others have calculated, and of course in accordance with Poynting's theorem.

The whole treatment here, with simple geometrical conceptions, is exceptionally interesting; and the resulting view of the nature of light—that it consists, as it were, of pulses running along the fibres as along stretched strings, with constant speed because their tension is proportional to their mass per unit length—is especially noteworthy, and is quite in accordance with a guess which the genius of Faraday enabled him to throw out in his famous "Thoughts on Ray Vibrations," where he says:—

"The view which I am so bold as to put forward considers therefore radiations as a high species of vibration in the lines of force which are known to connect particles and also masses together."

It is clear that if this vibrating string method of regarding waves of light be substantiated, a wave front cannot be a continuous surface, but must be, as it were, a series of isolated specks of disturbance; so also must a Röntgen pulse, and hence J. J. Thomson is able to reconcile with theory the actually experienced small ionising power of such waves, as compared with what might be expected if they really and necessarily encountered every atom in the field. They would, on the fibrous view, be in some respects more akin to a stream of kathode rays penetrating between the actual corpuscular particles of matter, and only encountering them occasionally, just as a comet or meteoric stone only occasionally encounters a planet.

One of the interesting features of the book—though it is also contained in another volume by the same author, "The Conduction of Electricity by Gases"—is the summary of a re-calculation of the results of Kaufmann's excellent experiments on the magnetic deflection of flying particles moving with very high velocity, such as can be shot off from radium. It is well known that Kaufmann proved that the mass of such charged bodies increases measurably as the speed approaches that of light; and by comparison of his results with theory he deduced, by aid of a fairly plausible assumption, that the electrical portion of the mass was about a quarter of the whole.

His assumption, however, had been that the charged particles behave like conducting spheres, so that the lines of force would at high speeds re-distribute themselves on their surface in accordance with the calculations of G. F. C. Searle for metal spheres.

J. J. Thomson, however, prefers to regard electron or corpuscular particles as behaving like perfect points, only points the field of which is non-existent within a certain small sphere surrounding each, which therefore constitutes the charged surface. On this view, the distribution of the lines on the bounding surface of the flying particle would obey a different law from that of a conducting sphere at high speed, and the result of a re-calculation is to make electrical mass *equal* to the whole mass, to a remarkable degree of approximation. Thus, for instance, when the speed is $2\cdot85 \times 10^{10}$ centimetres per second, the observed mass is measured as $3\cdot09$ times

the mass of the same particle for slow speed; calculation makes it 3.1 times. When the speed is $2.59 \times 10^{10}$, the observed mass ratio is 2.04; calculation makes it 2.0. When the speed is $2.36 \times 10^{10}$, observation gives the ratio 1.65, calculation 1.5, which is not quite so good an agreement; but even this is nearer than anyone could have anticipated, while the other results are extraordinarily close. If Kaufmann's results stand the test of criticism and repetition, they constitute a verification of a fact which is of the utmost importance and of the highest theoretical interest, for it has the effect of reducing the whole Matter in the universe to Electricity, not as a speculation, but as an established truth. It would be rash to jump to such an important conclusion too hastily; and there remains a great outstanding difficulty, hardly yet even faced, concerning the nature of positive electricity—that vague and cometary termination of lines which at the other end are intensely concentrated.

Moreover, the view taken by J. J. Thomson of the nature of the lines of force—whereby their momentum when moving depends upon the mass of ether vortically included in each and inseparable from it—cannot be said exactly to *explain* "mass." Material mass is first explained electrically, and then electrical mass is relegated to the inertia of ether,—not the great bulk of ether, which may be as regards locomotion immovable, but the core of the columnar vortices associated with and essentially constituting the particles of which atoms of matter are composed. The massiveness of ether itself would thus be an unexplained fundamental fact, and its density would have to be regarded as extremely great. The probably high density of ether had already been surmised by FitzGerald and others, and although by this means the cosmos is reduced to a kind of glorified hydrodynamics, yet the fundamental properties of the continuous fluid itself remain unexplained and to all appearance inexplicable.

This may be regarded as a defect, but, after all, explanation always proceeds by stages, reducing the complex to the simple and introducing unification; it can hardly be considered likely that any theory accessible to us here and now can give anything approaching an *ultimate* explanation even of the simplest thing. If the present theory can be substantiated, with whatever modifications and enlargements may be found to be necessary, it will be an immense step in advance; but it would be premature to suppose that these views are in any sense final, or that they will be promptly and universally accepted. They have been led up to by the progress of science during the last quarter century, and a welcome has been gradually prepared for some of them, but the discrete and real physical nature of the lines of force radiating from an electric charge seems to me a novelty; although, as said before, a fibrous vortex structure for the ether had already been suggested and shown to be competent to transmit transverse vibrations. This essential requirement for any ether, the transmission of transverse vibration, necessarily involves some "structure" in the ether, as Lord Kelvin and others have all along perceived. Lord Kelvin favoured at one time a laminar structure, FitzGerald a fibrous structure, and Hicks had his own conception of a vortex sponge. But the difficulty in most cases was to show that these arrangements were stable and could persist without mutual destruction or hopeless wire-drawing. It is not clear whether this difficulty has or has not yet been attacked by J. J. Thomson in connection with the pictorial representation which he now brings forward.

He shows clearly, somewhat on the same lines as Mr. Heaviside, how sudden jerks or accelerations given to the lines must result in radiation, and he makes many interesting thumb-nail calculations in connection with their behaviour, among other things showing that the mass of bound or associated ether in an electrostatic line is such that if moving with the speed of light it would exactly equal the electrostatic energy of the field per unit volume; though how an electric field is to be thus thought of in any *static* manner is not clear to me. Also he is able to regard the re-distribution of the lines of a charge in rapid motion (first calculated by Mr. Heaviside in the *Phil. Mag.*, April, 1889) as not only analogous to, but as really corresponding to, the tendency of a moving cylinder to set itself broadways to the direction of motion. Furthermore, the lines of force behave very exactly as stretched elastic threads; for though their section is not uniform, their tension, *i.e.* their total stretching force, varies everywhere with their mass per unit length, so that the rate of propagation of waves along them is constant.

Altogether a fascinating and most readable book for students of physics and chemistry.

OLIVER LODGE.

## SIR A. GEIKIE'S RECOLLECTIONS.

*Scottish Reminiscences.* By Sir Archibald Geikie. Pp. xii+447. (Glasgow: Maclehose and Sons, 1904.) Price 6*s*. net.

SCIENTIFIC readers will perhaps turn with most interest to the chapter in this charming book in which Sir Archibald, the last Scotchman for the time being who has directed the work of the Geological Survey of Great Britain, tells the story of the Scottish School of Geology. It is interesting to read along with it the pathetic lament of Principal Forbes, in Edinburgh, in 1862.

"It is a fact which admits of no doubt that the Scottish Geological School which once made Edinburgh famous, especially when the Vulcanist and Neptunian war raged simultaneously in the hall of this society"—the Royal Society of Edinburgh—"and in the class rooms of the University, may almost be said to have been transported bodily to Burlington House. Roderick Murchison, Charles Lyell, Leonard Horner, are Scottish names, and the bearers of them are Scottish in everything save residence—our younger men are drafted off as soon as their acquirements become known. Of all the changes which have befallen Scottish science during the last half century, that which I most deeply deplore, and at the same time wonder at, is the progressive decay of our once illustrious Geological School. Centralisation may account for it in part but not entirely."